TITLE

METHOD AND APPARATUS FOR ANALYZING MIXTURES OF GASES

Field of the Invention

This application claims the benefit of the filing date of U.S. Provisional Application No. 60/240,619, filed October 16, 2000, and of U.S. Provisional Application No. 60/246,946, filed November 9, 2000.

The present invention is a method and apparatus for sensing and analyzing certain gases, including NO_X, hydrocarbons, carbon monoxide and oxygen in a multi-component gas system using chemical sensors and chemical sensor arrays. The sensors and sensor arrays use chemo/electro-active materials to detect the presence of and/or calculate the concentration of individual gases within the multi-component gas system.

Technical Background

The use of chemical sensing devices to detect certain gases is known. Many attempts have been made to find a material with selectivity and sensitivity for a specific gas. For example, US 4,535,316 discloses a resistive sensor for measuring oxygen. See also H. Meixner et al, *Sensors and Actuators*, B 33 (1996) 198-202. It is apparent that different materials must be used for each gas to be detected. However, when a gas is part of a multi-component system, using one material to detect a specific gas is difficult because of the cross-sensitivities of the material to the various component gases of the mixture.

One example of a multi-component gaseous system is a combustion gas emission, which can include oxygen, carbon monoxide, nitrogen oxides, hydrocarbons, CO_2, H_2S, sulfur dioxide, hydrogen, water vapor, halogens and ammonia. See H. Meixner et al, Fresenius' *J. Anal. Chem.*, 348 (1994) 536-541. In many combustion processes, there is a need to determine whether the gas emissions meet requirements established by federal and state air quality regulations in various jurisdictions. Several types of gas sensors have been developed to

address this need. See US 5, 630,920, Friese et al, which discloses an electrochemical oxygen sensor; US 4,770,760, Noda et al, which discloses a sensor for detecting oxygen and oxides of nitrogen; and US 4,535,316, which discloses a resistive sensor for measuring oxygen. It would be advantageous to be able to simultaneously analyze two or more components of a mixture such as a combustion gas emission, to calculate concentration for example, in terms only of data generated by direct contact of the gases with a sensor and without having to separate any of the gases in the mixture. Prior art methods do not currently meet this need.

Numerous sensors have been disclosed to detect gases evolving from foods and from other relatively low temperature applications. See K. Albert et al, *Chem. Rev.*, 200 (2000) 2595-2626. Arrays of several undoped and doped tin oxide sensors have also been disclosed for use in detecting various combustion gases up to 450°C. See C. Di Natale et al, *Sensors and Actuators*, B 20 (1994) 217-224; J. Getino et al, *Sensors and Actuators*, B33 (1996) 128-133; and C. Di Natale et al, *Sensors and Actuators*, B 23 (1995) 187-191. However, at higher temperatures and in the highly corrosive environment in which one would use chemical sensors to monitor combustion gases, operating temperature can alter or impair the performance of the sensor array. That being the case, high temperature environments require the use of materials that are both chemically and thermally stable and that maintain measurable responses to the gases of interest. The effect of the operating temperature on the response of tin oxide bases sensor arrays was studied up to 450°C. See C. Di Natale, *Sensors and Actuators* B23 (1995) 187-191. However, materials in addition to those previously known in the art are still needed to be able to provide a method and apparatus capable of directly monitoring the gas emissions of multi-component gas systems at

higher temperatures, such as would be encountered in the operation of combustion gas systems.

Addressing this need would permit the use of a chemical sensor to measure combustion emissions, such as automobile exhausts, and determine whether those emissions meet functional and mandated requirements. In addition, it has surprisingly been found that the method and apparatus of this invention that are useful for analyzing high temperature gases, such as automotive emissions, may be employed with equal effect in analyzing low temperature gases.

Summary of the Invention

This invention provides a method for directly sensing gas components in a multi-component gas system, comprising the steps of: (i) exposing a chemical sensor comprising an array of at least two chemo/electro-active materials to a multi-component gas system, detecting a response, and directly measuring the response of each chemo/electro-active material. Preferably the chemo/electro-active material is a semiconducting material, and the multi-component gas system is a combustion process emission. The response that is measured can be a measurement of capacitance, voltage, current, AC impedance, or DC resistance.

This invention also provides a chemical sensor for directly sensing the presence of gas components in a multi-component gas system, comprising a substrate; an array of at least two chemo/electro-active materials on said substrate; and a means for detecting a response from said chemo/electro-active materials when exposed to said analyte gas component(s) in the system. Preferably the chemo/electro-active material is a semiconducting material, and the multi-component gas system is a combustion process emission. The response that is detected can be an electrical property such as capacitance, voltage, current, AC impedance, or DC resistance. The device can additionally contain a housing, means for measuring the detected responses,